

NASA
Engineering Directorate
Materials Science Division
Kennedy Space Center, Florida

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SUBJECT: Post STS-133 Evaluation of Main Flame Deflector Witness Materials

CUSTOMER: Wulf Eckroth / United Space Alliance (USA) / USK-751

1. ABSTRACT

NASA and USA Structures engineers submitted main flame deflector witness materials for evaluation after the launch of STS-133. The following items were submitted for analysis: HY-80 steel witness rods, 304 stainless steel caps, tungsten pistons, 17-4 precipitation hardened (PH) stainless steel and A-286 piston sleeves, Medtherm Corporation calorimeters, and Nanmac Corporation thermocouples. All of the items were photographed in order to document their condition after the launch of STS-133, and before they were reinstalled at the launch pad for future launches. The HY-80 witness rods, 304 stainless steel caps, and the piston sleeves were dimensionally measured in order to determine the amount of material lost during launch. Microstructural changes were observed in the HY-80 witness rod and 304 stainless steel cap metallographic samples due to the heat of the launch.

2. FOREWORD

Materials tested in the main flame deflector at Launch Complex (LC) 39A during the launch of STS-133 on February 24, 2011, were submitted for evaluation. The materials were analyzed in order to determine their suitability for use in the main flame deflector as an alternative to the refractory material currently used on the flame deflector during launch. The purpose of the investigation was to evaluate the condition of the material after being subjected to the blast of one launch. The requested analyses included photo-documentation, dimensional measurements, and metallography in order to determine the wear profile and mechanism for the different materials. A customer-supplied matrix of the submitted samples and the requested objectives is listed in Table 1. For each sample type, a different sample was submitted for each of the locations listed in Table 1, which indicates their relative testing location on the main flame deflector. Additional samples were submitted prior to launch in order to establish a baseline condition of the different materials used for the tested samples.

Table 1. Testing matrix and objectives for each of the samples submitted.

Sample Type	Sample Locations	Objective
HY-80 Witness Rods	Top Hole Middle Bottom	Determine erosion profile Determine if erosion or melting of material occurred for Top Hole and Bottom samples
304 Stainless Steel Caps	Top Hole Middle	Determine erosion profile Determine if erosion or melting of material occurred
Tungsten Pistons	Top Hole Middle Bottom	Document cracks
17-4 PH and A-286 Piston Sleeves	Top Hole Middle Bottom	Document erosion profile
Medtherm Calorimeters*	Top Hole Middle Bottom	Determine internal makeup Determine erosion profile
Nanmac Thermocouples*	Top Hole Middle Bottom	Determine internal makeup

*Samples to be analyzed separately in a separate study.

3. PROCEDURES AND RESULTS

3.1. The submitted samples were photographed, as received (Figures 1-11). The amount of erosion varied by sample and by location on the flame trench. The bottom and top locations of the HY-80 witness rods were selected for further testing because they displayed visible erosion (Figures 1 and 3). Both of the 304 stainless steel caps displayed significant material loss, which exceeded the erosion observed on the HY-80 witness rods (Figures 4 and 5). The tungsten pistons did not have a considerable amount of erosion, but cracks were observed on the sides of the pistons (Figures 6 and 7). The piston sleeves were also photo-documented, and did display some erosion on their exposed surfaces (Figures 8-11). The 6 o'clock position is noted for each sample and was either designated by the customer or selected in the laboratory in order to have a reference point for dimensional measurements.

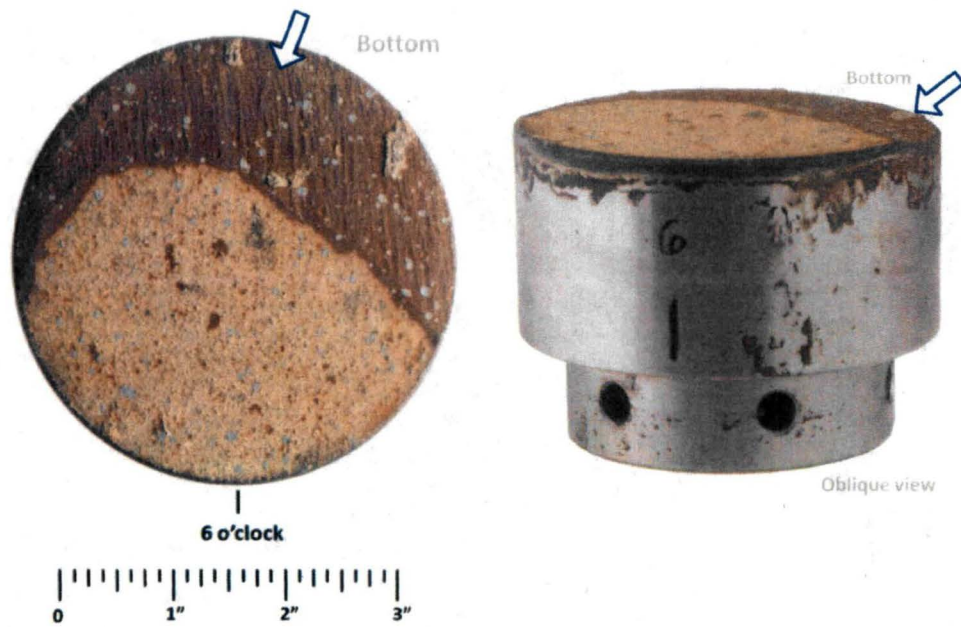


Figure 1. Bottom HY-80 witness rod, as-received. Arrows indicate location of erosion. The 6 o'clock position on this sample was chosen in the laboratory since the customer had not designated a reference position for dimensional measurements. Scale is three inches.

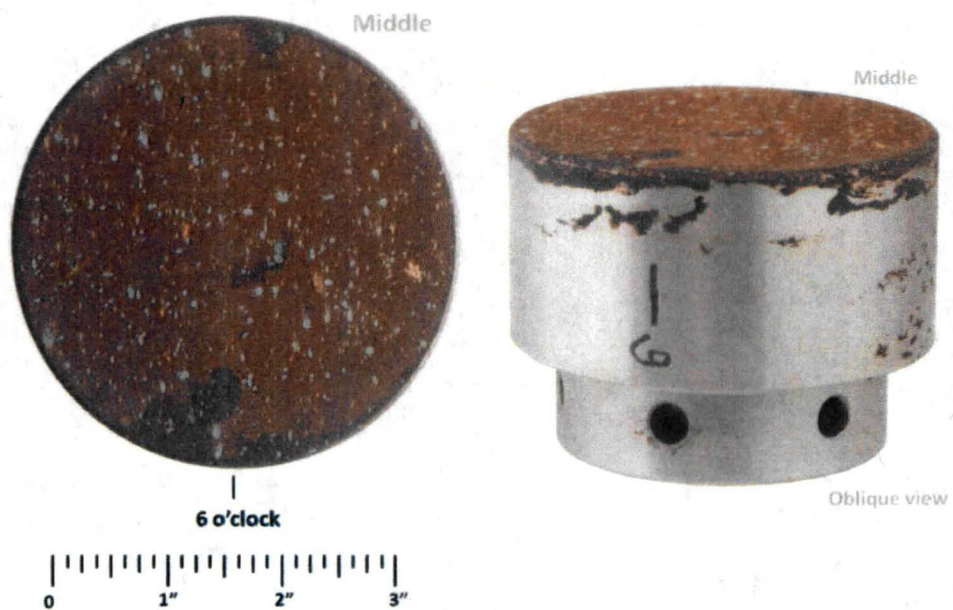


Figure 2. Middle HY-80 witness rod, as-received. The 6 o'clock position was designated by the customer. Scale is three inches.

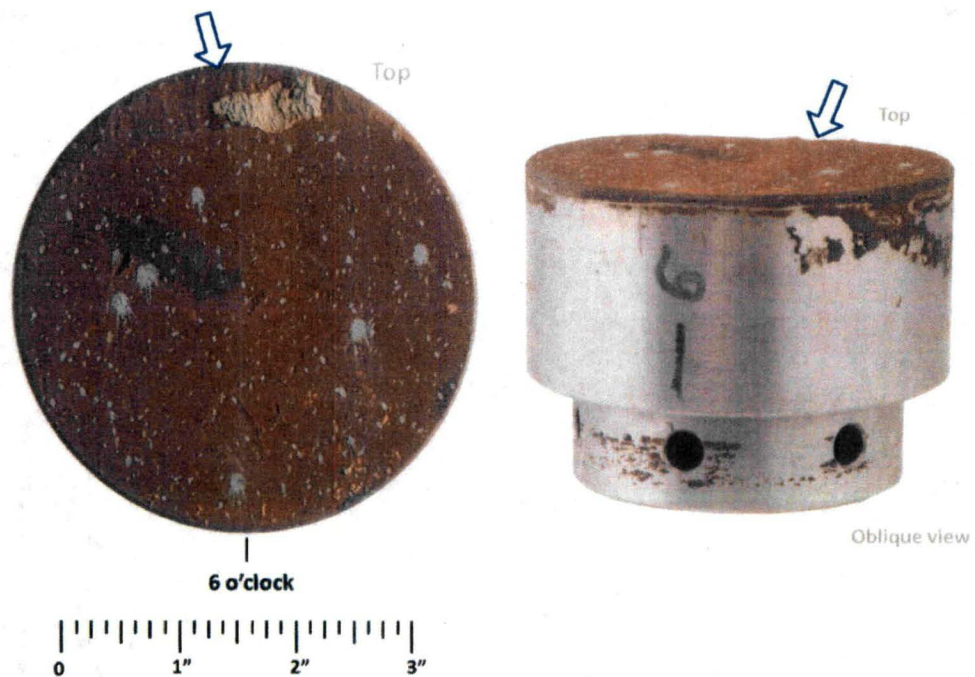


Figure 3. Top HY-80 witness rod, as received. Arrows indicate location of erosion. The 6 o'clock position was designated by the customer. Scale is three inches.



Figure 4. Middle 304 stainless steel cap, as received. Arrows indicate location of erosion. The 6 o'clock position on this sample was chosen in the laboratory since the customer had not designated a reference position for dimensional measurements. Scale is three inches.

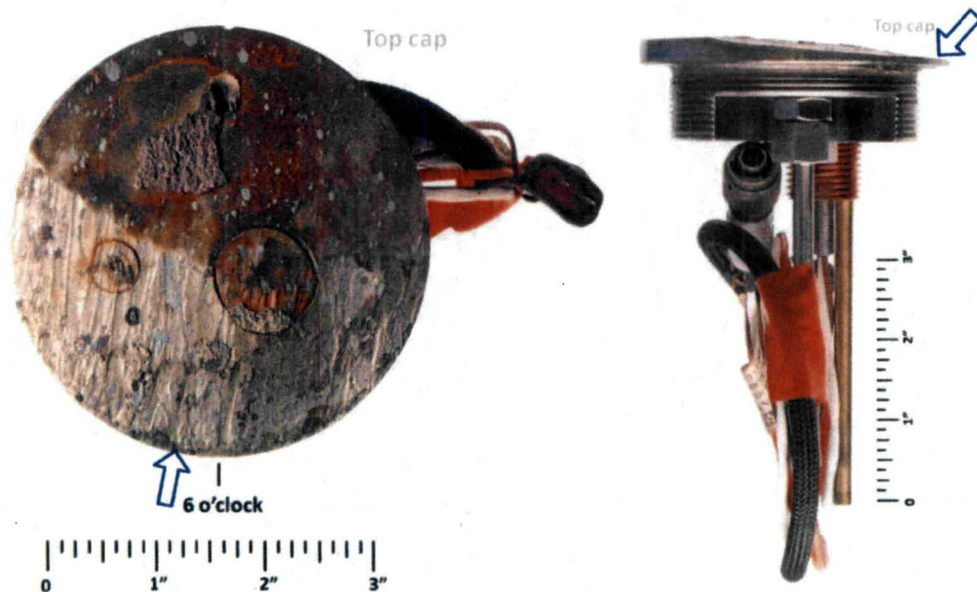


Figure 5. Top 304 stainless steel cap, as received, with instrumentation still attached. Arrows indicate location of erosion. The 6 o'clock position on this sample was chosen in the laboratory since the customer had not designated a reference position for dimensional measurements. Scales are three inches.

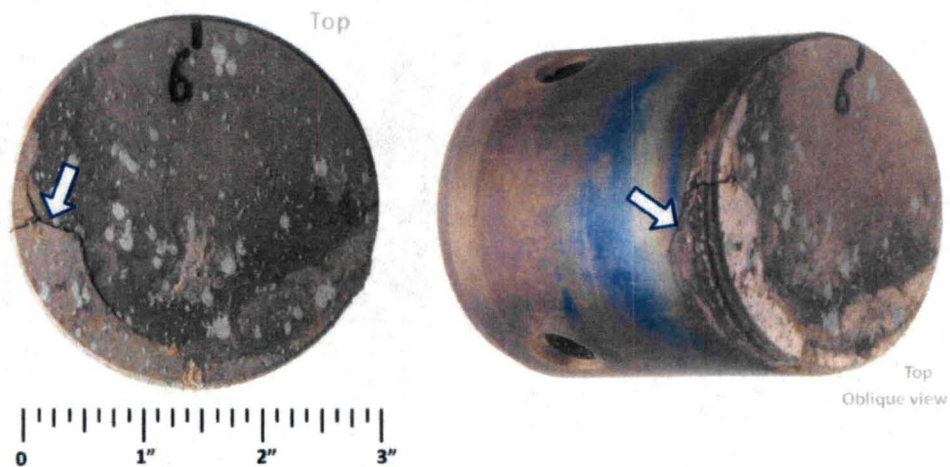


Figure 6. Top tungsten piston, as received. The arrows indicate the location of cracks observed on the piston. Pictures are representative of the other two pistons. Scale is three inches.

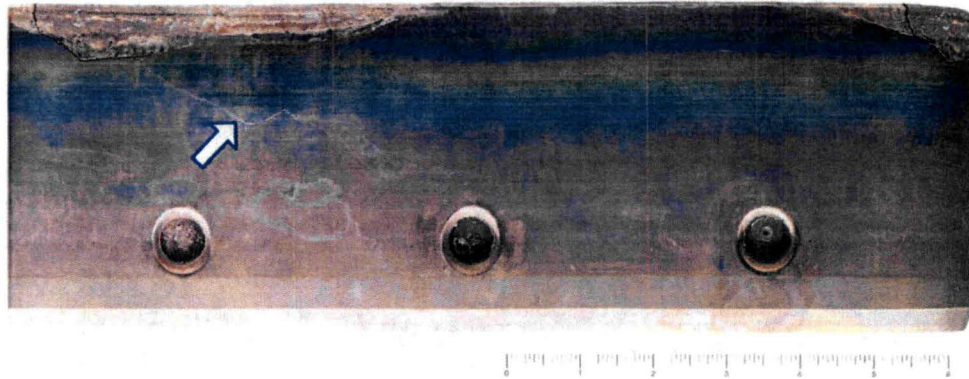


Figure 7. 360° montage image around the side of the top tungsten piston, showing the crack around the outer surface (arrow). Scale is six inches.

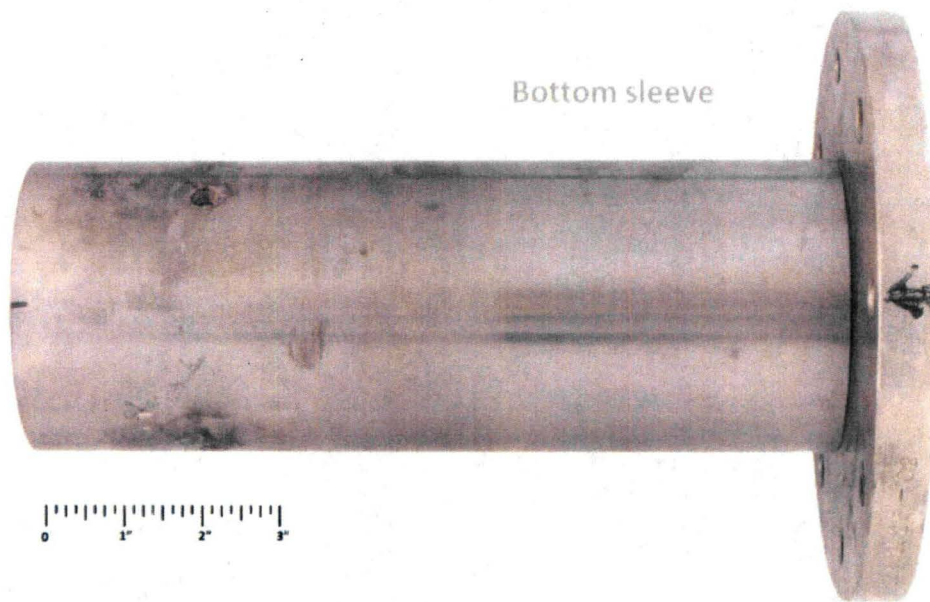


Figure 8. Bottom 17-4 PH piston sleeve, as received. Scale is three inches.

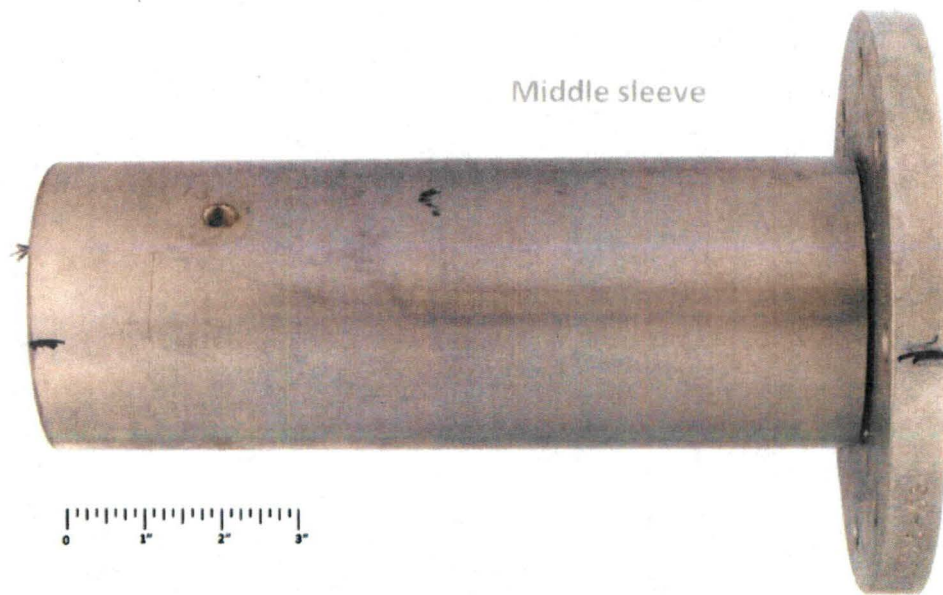


Figure 9. Middle A-286 piston sleeve, as received. Scale is three inches.

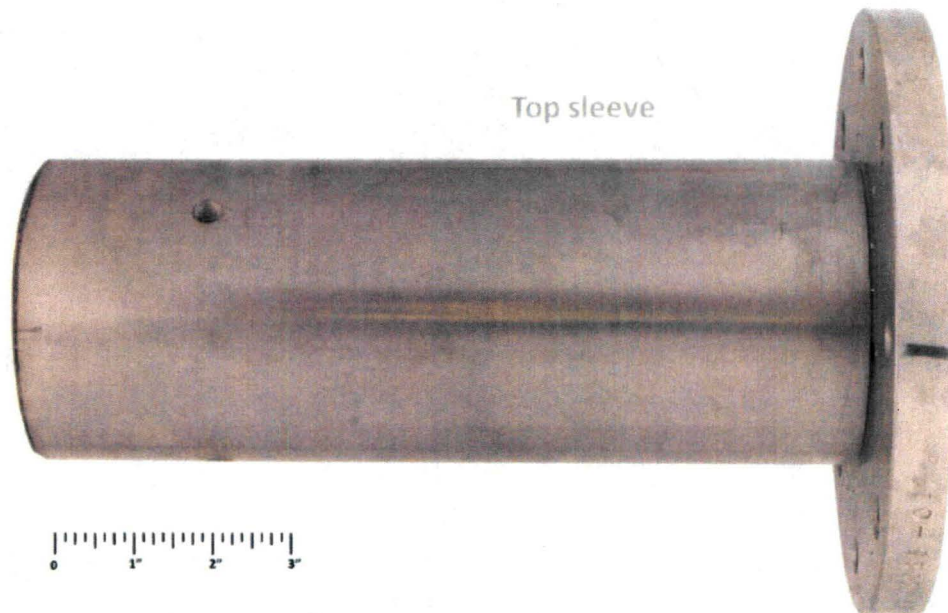


Figure 10. Top A-286 piston sleeve, as received. Scale is three inches.

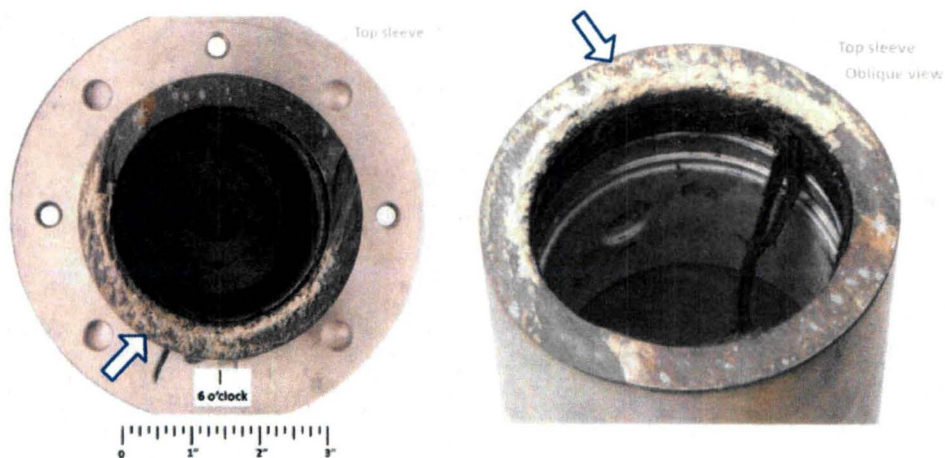


Figure 11. Top piston sleeve, as received, showing the location of the erosion (arrows). Pictures are representative of the other two piston sleeves. Scale is three inches.

- 3.2. The HY-80 witness rods, 304 stainless steel caps, and the piston sleeves were dimensionally measured in order to determine their erosion profiles. Each of the samples was measured using a Micro-Vu optical coordinate measuring machine (CMM) with an accuracy of ± 0.008 inch. The thicknesses were measured at four places around the periphery of the sample, at the 12, 3, 6, and 9 o'clock positions. The bottom sample was additionally measured at the 2 o'clock position due to a notable difference in the thickness at this location. The measurements are listed in Tables 2 through 4, along with the average thickness, maximum thickness, minimum thickness, and max-min difference. All measurements are listed in inches. The customer supplied original thickness measurements for the HY-80 witness rod samples.

Table 2. HY-80 Witness Rod Measurements

Measurement Location	Top Sample Thickness	Middle Sample Thickness	Bottom Sample Thickness
Original thickness	2.000	2.001	1.998
12 O'Clock	1.9337	2.0119	1.9132
2 O'Clock	N/A	N/A	1.8625
3 O'Clock	2.0067	2.0050	1.8828
6 O'Clock	2.0037	2.0047	2.0054
9 O'Clock	2.0124	2.0041	1.9422
Average	1.9891	2.0064	1.9212
Maximum	2.0124	2.0119	2.0054
Minimum	1.9337	2.0041	1.8625
Difference	0.0787	0.0078	0.1429

Table 3. 304 Stainless Steel Cap Measurements

Measurement Location	Top Sample Thickness	Middle Sample Thickness
12 O'Clock	0.3128	0.3091
3 O'Clock	0.2473	0.2646
6 O'Clock	0.0692	0.0849
9 O'Clock	0.1944	0.2825
Average	0.2059	0.2353
Maximum	0.3128	0.3091
Minimum	0.0692	0.0849
Difference	0.2435	0.2242

Table 4. Tungsten Piston Sleeve Measurements

Measurement Location	Top Sample Thickness	Middle Sample Thickness	Bottom Sample Thickness
12 O'Clock	11.6960	11.6983	11.7135
3 O'Clock	11.5859	11.7025	11.7131
6 O'Clock	11.5068	11.5190	11.6013
9 O'Clock	11.5981	11.6412	11.7178
Average	11.5967	11.6402	11.6864
Maximum	11.6960	11.7025	11.7178
Minimum	11.5068	11.5190	11.6013
Difference	0.1891	0.1835	0.1165

- 3.3. The bottom and top HY-80 witness rod samples were cross-sectioned in the area with the observed erosion, mounted in acrylic resin, and prepared for metallographic examination. Both samples displayed a transformed layer due to heating of the metal during launch, followed by quenching due to the water deluge. These heat affected zones in both samples consisted of untempered martensite with possible minor amounts of bainite (Figures 12 and 13, left side of image). The heat affected zones displayed observable difference in the microstructure as a function of depth, which was likely due to differences in the amount of time spent in transition during quenching of the surface of the witness rod. The parent metal consisted of tempered martensite (Figures 12 and 13, right side of image). The heat affected zone was approximately 0.1 inch (2.5 mm) deep in the bottom sample and 0.06 inch (1.5 mm) deep in the top sample. High

magnification observation at the surface of the witness rod revealed no apparent indications of melted metal, such as dendrites or distorted grains (Figure 14). The possibility of melting is not likely, but could not be eliminated because the melted metal could have been removed from the surface due to the launch blast.

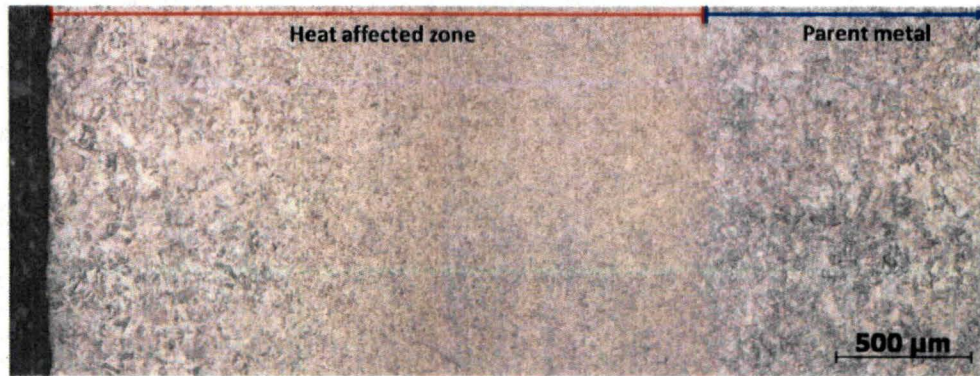


Figure 12. Micrograph of the surface (left) of the bottom sample HY-80 witness rod showing the untempered martensite in the heat affected zone and tempered martensite in the parent metal. The observable differences in microstructure in the heat affected zone are likely due to differences in the amount of time spent in the transition during quenching, with minor amounts of bainite possibly present. Etchant: diluted nital. Original magnification: 100X



Figure 13. Micrograph of the surface (left) of the top sample HY-80 witness rod showing the untempered martensite in the heat affected zone and tempered martensite in the parent metal. Etchant: diluted nital. Original magnification: 100X

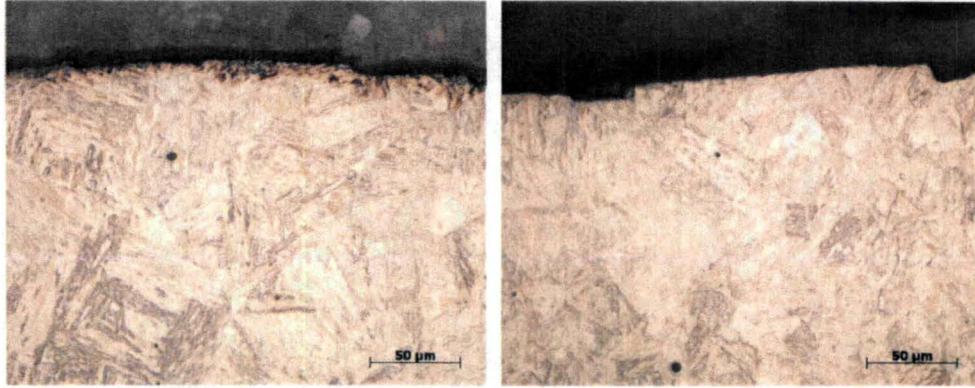


Figure 14. Micrographs at the surface of the bottom sample (left) and top sample (right) showing the grain structure in these locations. No apparent indications of melting and resolidification of the metal are present. Note: The discoloration at the surface of the bottom sample is an etching artifact, not a microstructural difference. Etchant: diluted nital. Original magnifications: 500X

- 3.4. In order to confirm the microstructural changes that were observed in the HY-80 witness rods, microhardness measurements were taken on the metallographic specimens using a Vickers indenter with a 500 g load every 0.5 mm, starting near the surface of the witness rod. The measurements were then converted to Rockwell C scale (HRC) per ASTM E 140, *Standard Hardness Conversion Tables for Metals*. The average hardness in the heat affected zone was 42 HRC, which is typical for untempered martensite in HY-80 steel. The average hardness in the parent metal was 22 HRC, which is typical for tempered martensite in HY-80 steel. The hardness values were distinctly different in the transformed region versus the parent material with a sharp difference in hardness right at the transition line (Figure 15). The hardness values also correlated with the metallographic observation of a thicker heat affected zone in the bottom sample occurring approximately 0.1 inch (2.5 mm) into the sample versus the 0.06 inch (1.5 mm) deep transformation observed in the top sample.

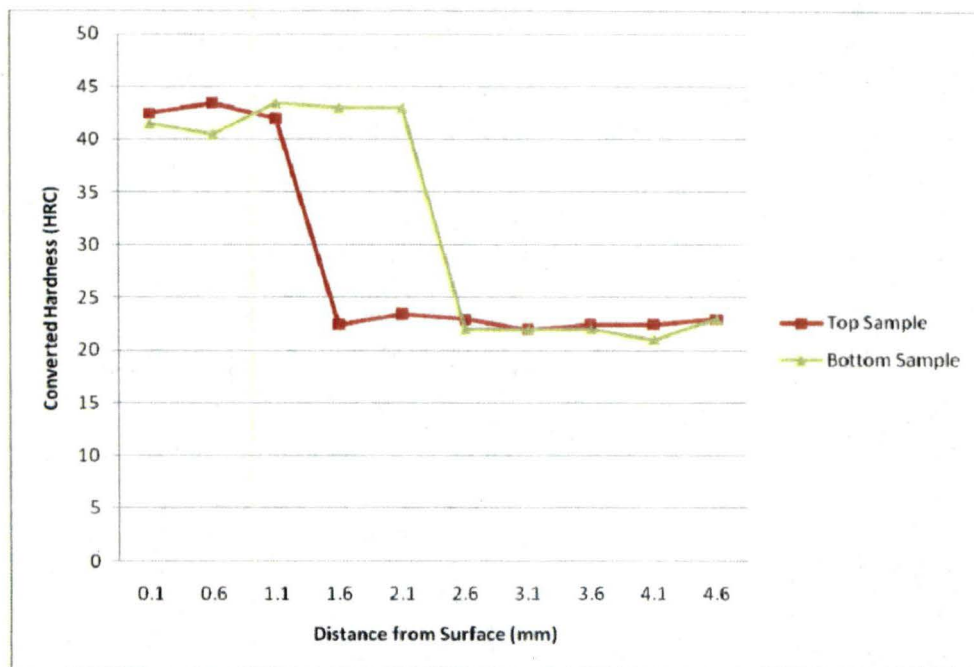


Figure 15. Converted hardness values as a function of depth in the HY-80 witness rods.

- 3.5. The middle and top 304 stainless steel cap samples were cross-sectioned in the area with the observed erosion, mounted in acrylic resin, and prepared for metallographic examination. Both samples displayed a layer of melted and resolidified metal that was approximately 50 microns thick, as indicated by the dendritic microstructure in this location (Figure 16, arrows). The caps displayed an austenitic grain structure in the areas that had not melted, which is typical for 304 stainless steel (Figure 16). The grain structure just below the melted layer was larger than it was in the parent metal, which was caused by the heat imparted on the cap during launch (Figure 16, right). This affect of heat on the microstructure was observed approximately 0.5 mm into the depth of the material.

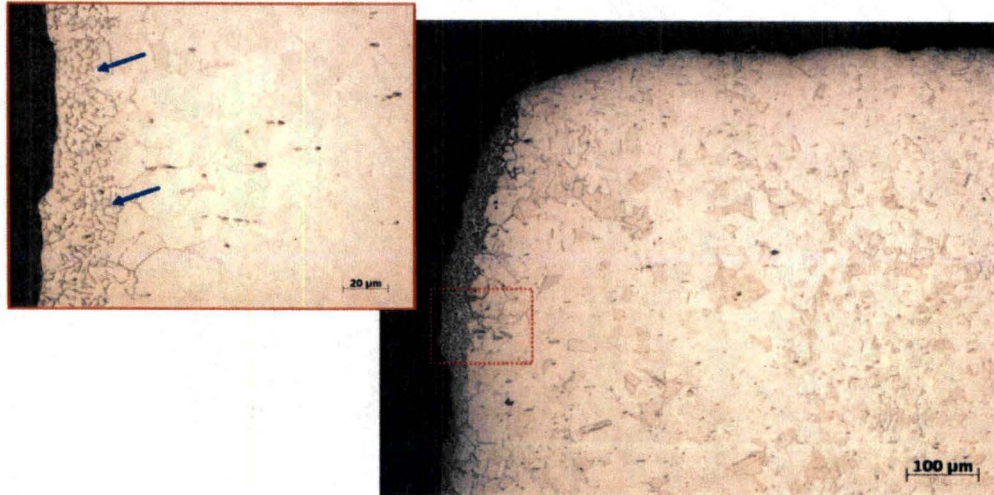


Figure 16. Micrograph of the middle 304 stainless steel cap showing an approximately 50-micron thick layer of melted and resolidified metal at the surface, as indicated by the dendritic microstructure (arrows). The base metal had a typical austenitic grain structure, with larger grains near the surface due to the effects of heating during launch. Micrograph is representative of both the 304 stainless steel cap metallographic samples. Etchant: 10% oxalic, electrolytic. Original magnifications: 500X (boxed), 100X (right).

4. CONCLUSION

- 4.1. The HY-80 witness rod samples were photographed, measured for dimensional changes, evaluated for microstructural differences, and tested to determine the microhardness profile. The bottom and top witness rod samples had visible erosion occur on the exposed surface of the witness rod. The bottom and top samples exhibited a transformation of the microstructure to untempered martensite in the heat affected zone at the surface of the witness rod due to heating during launch and quenching during water deluge. This transformation was confirmed by a significant increase in the hardness of the heat affected zone compared to the hardness of the tempered martensite in the parent metal. The bottom sample had a heat affected zone that was approximately 0.1 inch (2.5 mm) deep and the top sample had a heat affected zone that was approximately 0.06 inch (1.5 mm) deep. No apparent indications of melting were observed in the microstructure; however, the launch blast could have removed any evidence of melting.
- 4.2. The 304 stainless steel cap samples were photographed, measured for dimensional changes, and evaluated for microstructural differences. Both the bottom and top caps displayed a layer of melted and resolidified metal that was approximately 50 microns deep. An additional 0.5 mm thick layer of the sample was affected by the heat of launch, as indicated by grain growth in this location.

- 4.3. Differences in sample location and the amount of material in the different types of samples could have contributed to why the 304 stainless steel caps melted and the HY-80 witness rods likely did not. Although the melting temperature difference between 304 stainless steel and HY-80 is not that great, the witness rod samples had significantly more mass and would require more heat to melt. Although no direct evidence of melting was observed in the microstructure of the HY-80 witness rod samples, the possibility cannot be eliminated due to the dynamic conditions present in the flame trench during launch.
- 4.4. The tungsten pistons and the stainless steel piston sleeves were photographed in order to document their condition after one launch. The piston sleeves were also dimensionally measured in order to document the amount of erosion caused by one launch.

EQUIPMENT: Micro-Vu Optical CMM Excel, ECN-2237258
Zeiss Z1m Metallograph, S/N 3837000175
Struers Duramin Microhardness Tester, S/N 5640020

RELATED DOCUMENTATION: ASTM E 140, *Standard Hardness Conversion Tables for Metals*

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